353

No

MSC INTERNAL NOTE NO. 66-EG-23

PROJECT APOLLO

EFFECT OF LEM LANDING RADAR ERRORS AND SLOPING TERRAIN ON PHASE II FLIGHT OF THE LEM POWERED DESCENT

Prepared by: Thomas G. Price, Aerospace Engineer
Theoretical Mechanics Branch

Approved: Jack Funk, Chief
Theoretical Mechanics Branch

Approved: Robert G. Chilton
Deputy Chief, Guidance and
Control Division

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

April 27, 1966

SUMMARY

A study is presented on the effect of LEM landing radar errors and a sloping lunar terrain on terminal conditions of the LEM powered descent, and on variations in the guidance commands. Only Phase II flight (from hi-gate to lo-gate) is investigated. This study indicates that landing radar errors of ±5% or ±2 deg sloping lunar terrain can be accommodated by the guidance equations.

INTRODUCTION

The LEM powered descent is divided into three phases (see figure 1): an initial braking phase (Phase I); a final approach phase (Phase II); and the landing phase (Phase III). Phases I and II of the LEM powered descent are guided by a set of equations which are reported in reference 1. The landing approach flight is a constant thrust and constant attitude trajectory designed to allow adequate fuel economy, pilot control, and pilot visibility of the landing area, as presented in reference 2. The initial and final conditions and the time of flight of Phase II are predetermined to yield the constant thrust and constant attitude phase of flight. However, if the LEM landing radar should be in error, or the lunar terrain not be flat, then the constancy of the thrust and attitude would be destroyed. A landing radar error would correspond to a change in the initial conditions, and a sloping terrain would correspond to an error in the present position. It is the purpose of this paper to investigate the effect of LEM landing radar errors and a sloping lunar terrain on terminal conditions of the LEM powered descent and on variations in the guidance commands.

SCOPE OF CALCULATIONS

The study presented in this paper was conducted with the linear acceleration guidance equations (see reference 1) with no recalculation of the nominal time-to-go. Altitude and velocity radar errors of ±5% to -5% were considered. Since only Phase II flight was investigated, the altitude weighting factor for the radar update of the IMU was assumed to be 1.0. That is, the radar altitude information was assumed to be correct. The velocity weighting factor was assumed to vary linearly between 0.0 at 5,000 ft altitude to 1.0 at 3,000 ft altitude. Several cases were considered for a sawtooth velocity radar error which varied linearly over different time intervals from +5% to -5%. This radar error may not be realistic, but is included as a severe case that should produce the greatest guidance command variations. Lunar terrain slopes of +2 deg to -2 deg were considered which had a maximum terrain variation both initially and terminally. When there was a terrain variation, the landing radar accuracy was assumed to be 100%.

RESULTS AND DISCUSSION

Effect on Terminal Conditions

To ascertain the effects due only to the landing radar errors, a flat lunar terrain was assumed when radar errors were used. A time history of the nominal trajectory used for the investigation is presented in figure 2. The errors in the terminal altitude and velocity, neglecting dynamic effects, should be the same percentage of the final altitude and velocity as the corresponding percentage radar error. This means that at 700 feet altitude with 62 fps velocity and a ±5% radar error for both variables, errors of ±35 ft for altitude, and about ±3 fps for velocity would be expected. Because of variations in the guidance commands and the coupling of the altitude and velocity radar errors, the maximum error for the terminal altitude was about ±50 ft and for the terminal velocity was about ±5 fps. The effect on delta v required was found to be the inverse of the velocity error; i.e., if the terminal velocity is 5 fps high, then the delta v would be 5 fps low.

To obtain the effects due to a terrain variation, a sloping lunar terrain of +2 deg to -2 deg was used. The positive and negative slopes were both used with a high and low initial and final altitude as shown in figure 3 (a), (b),(c) and (d). The variations in the terminal velocity and the delta v required were negligible, but the terminal altitude error was a maximum of about ±30 ft. Figure 3 shows an altitude vs range profile for the 2 deg cases, both positive and negative slopes. Even when there was a high or low terminal altitude the guidance equations guided to a final altitude of about 700 ft.

Effect of Radar Errors on Guidance Commands

Radar Altitude Errors.- Variations in the guidance commands are presented in figure 4(a) and (b) for altitude radar errors of ±5%. Pitch angle variations (relative to the local vertical) are shown in figure 4(a) to be less than ±2 deg and figure 4(b) shows that the thrust level does not vary over ±200 lbs. R_{ERR} is the percentage altitude radar accuracy.

Varying Radar Velocity Error.- Shown in figure 5(a) and (b) are the guidance variations for a sawtooth velocity radar error, where V_{ERR} is the percentage velocity radar accuracy. Figure 5(c) presents the manner in which the velocity radar was varied throughout the Phase II flight. The largest variation of the pitch angle (figure 5(a)) was about 6 deg and for the thrust level (figure 5(b)) was about 700 lbs. Since the nominal trajectory has a look angle 10 deg above the lower window limit, this may allow only 4 deg visibility instead of the desirable 10 deg. Also, the thrust level increases to about 6000 lbs which is approaching the 60% limit of 6300 lbs.

Combined Radar Altitude and Velocity Errors.- Variations of the guidance commands for combined constant radar errors in both the altitude and velocity information are presented in figure 6(a) and (b). These variations at the maximum are about 3 deg for the pitch angle and about 700 lbs for the thrust level, which is approaching the throttle limit of 60% as stated in the preceding paragraph.

Effect of Sloping Terrain on Guidance Commands

The guidance command variations for the four trajectories, a, b, c, and d, are presented in figure 7(a) and (b). Trajectories (c) and (d) which had a low and high initial altitude, respectively, are analogous to about a 10% initial altitude radar error which decreased to 0% error at termination. The maximum pitch angle variation (see figure 7(a)) was about 3° and the thrust level varied by about 300 lbs. (See figure 7(b)).

These variations are expected to be within the operational constraints of the LEM powered descent. Therefore, this brief investigation indicates that landing radar errors of ±5% or a 2-deg sloping lunar terrain can be accommodated by the guidance equations used for this study. Even though these equations are not the same as the current LEM descent guidance equations the results would be applicable. This is because the major difference is the recalculation of the time-to-go each integration step, and this calculation is based on a calculated jerk, the desired terminal jerk, and the derivative of the final jerk. The calculated jerk is a function of position and velocity, but the variation of the time-to-go due to this jerk would be negligible.

CONCLUDING REMARKS

A study was presented of the effect of LEM landing radar errors and a sloping lunar terrain on terminal conditions of the LEM powered descent and on variations in the guidance commands. Only Phase II flight (from hi-gate to lo-gate) was investigated. This study indicated that landing radar errors of ±5% or a ±2-deg sloping lunar terrain can be accommodated by the guidance equations.

REFERENCES

1. Cherry, George W.: "A Class of Unified Explicit Methods for Steering Throttleable and Fixed-Thrust Rockets," MIT/IL Report R-417, (Rev. 1964).

2. Bennett, Floyd V.; Price, Thomas G.: "Study of Powered-Descent Trajectories for Manned Lunar Landings," NASA TN D-2426, 1964.

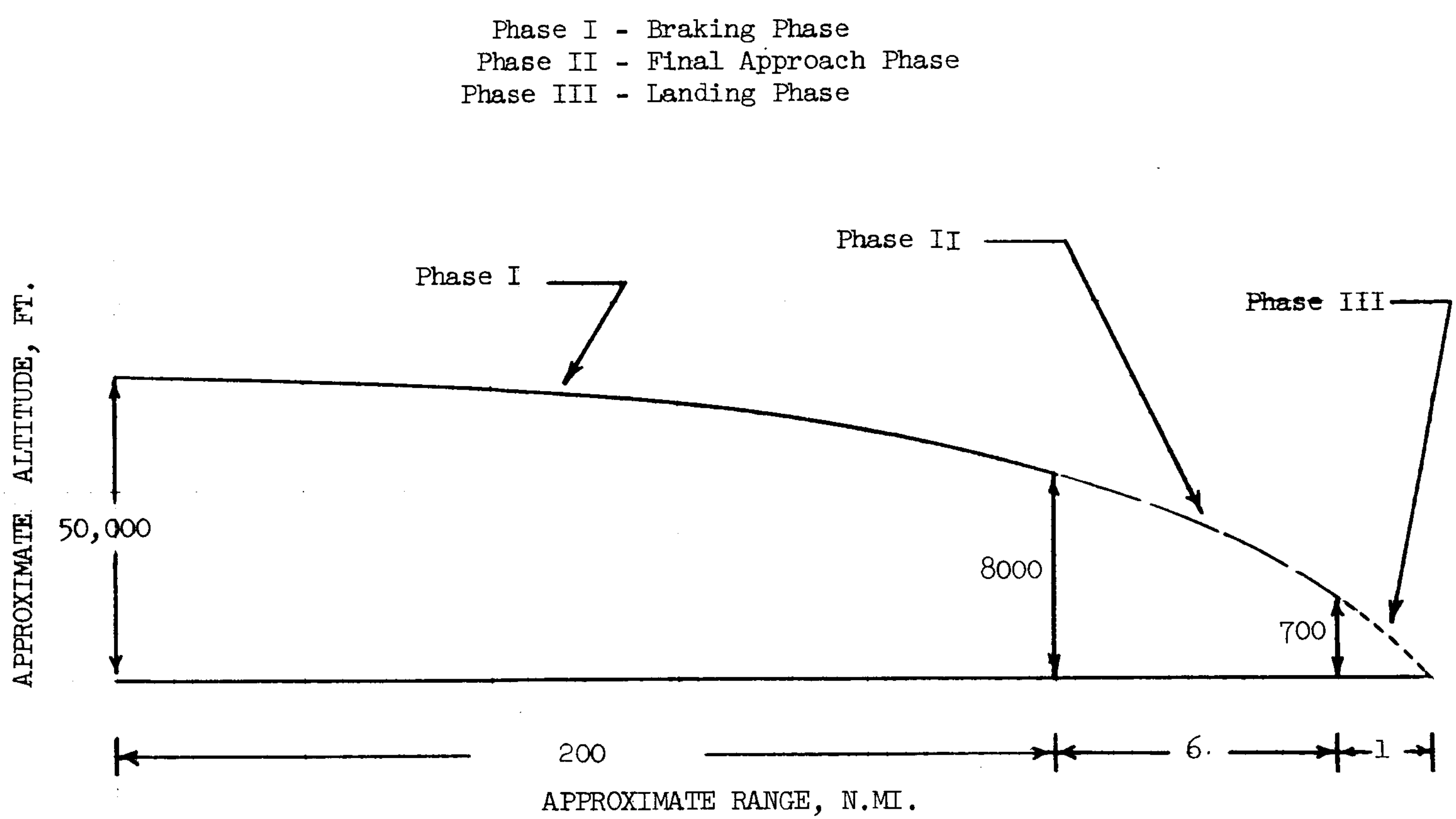


Figure 1.- Three phases of powered descent.

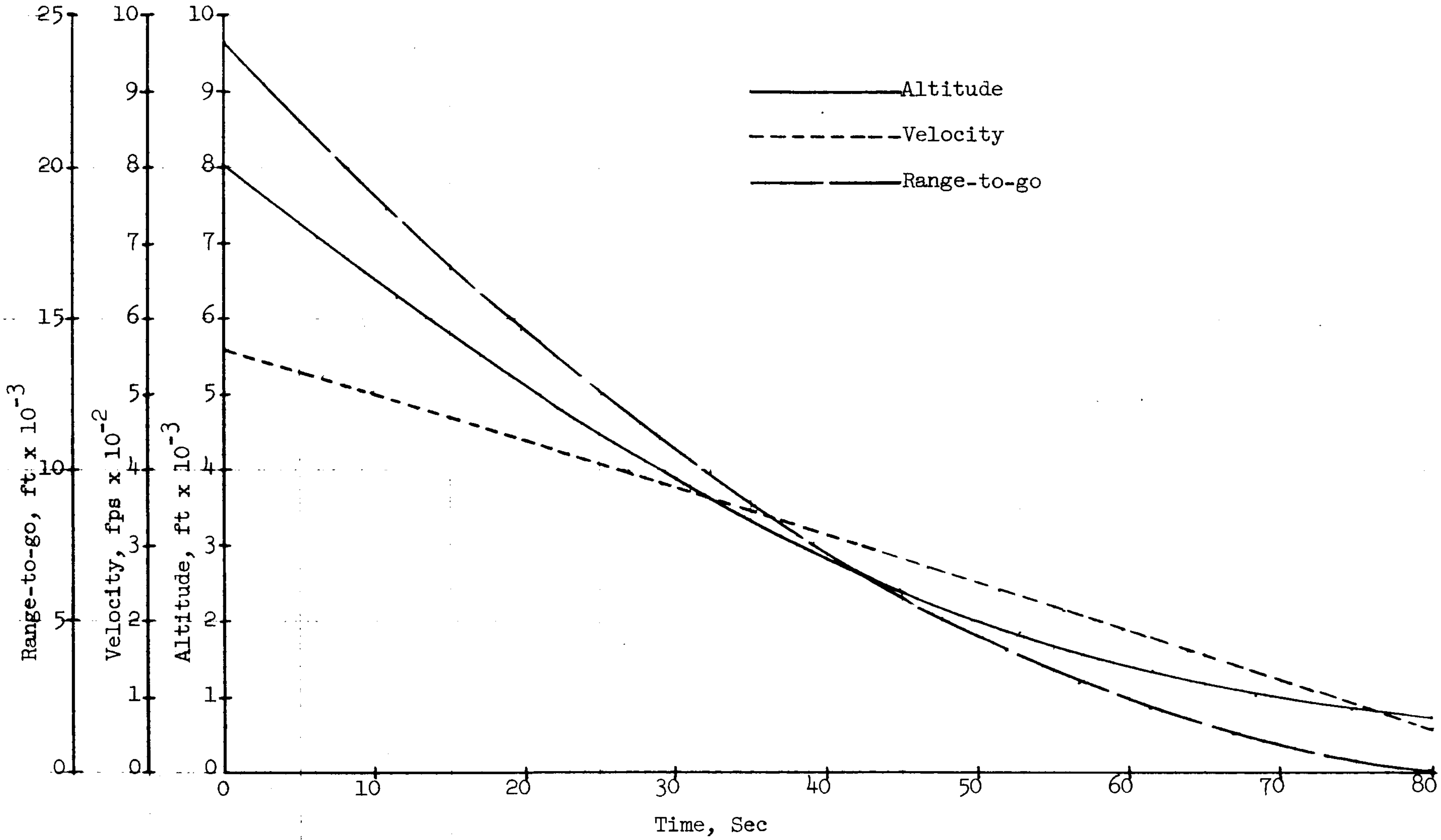
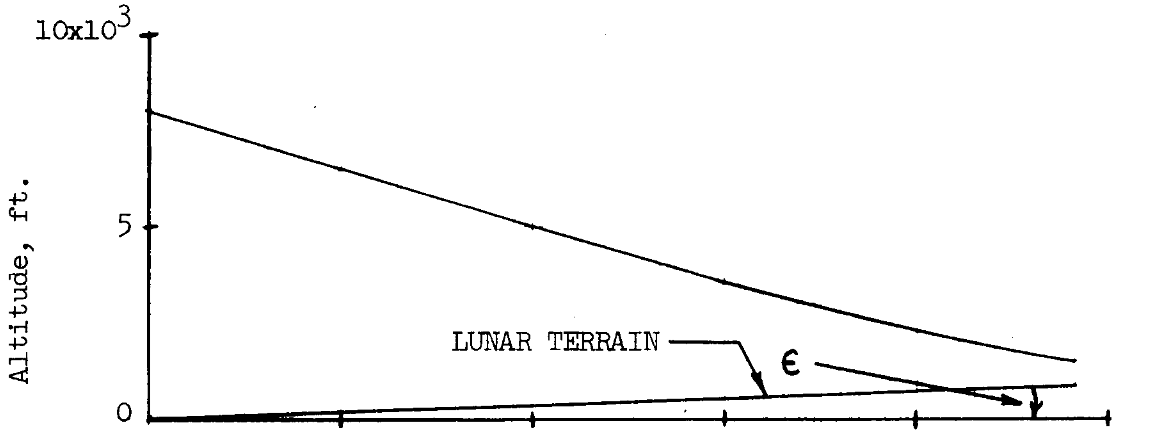
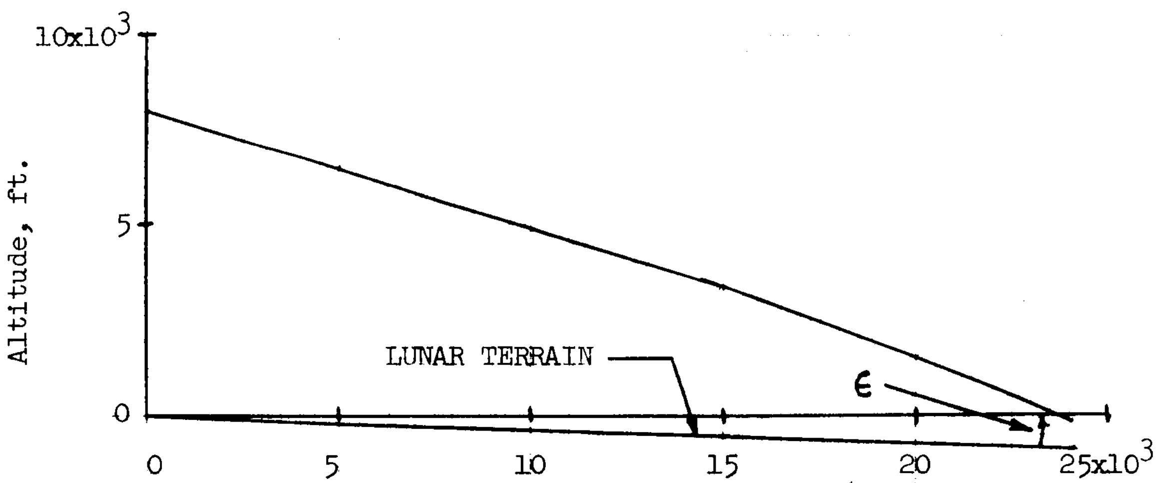


Figure 2.- Time history of nominal trajectory



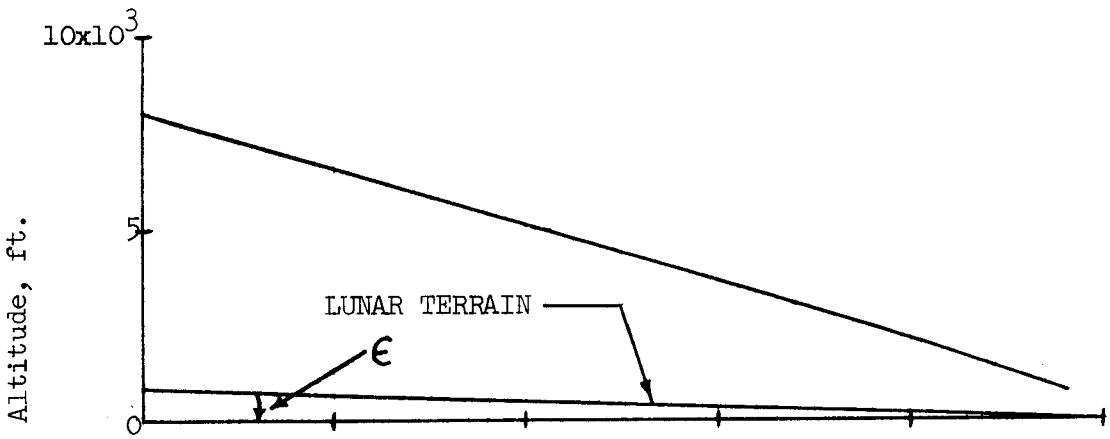
(a) Positive slope - high terminal altitude

ϵ = 2 deg.



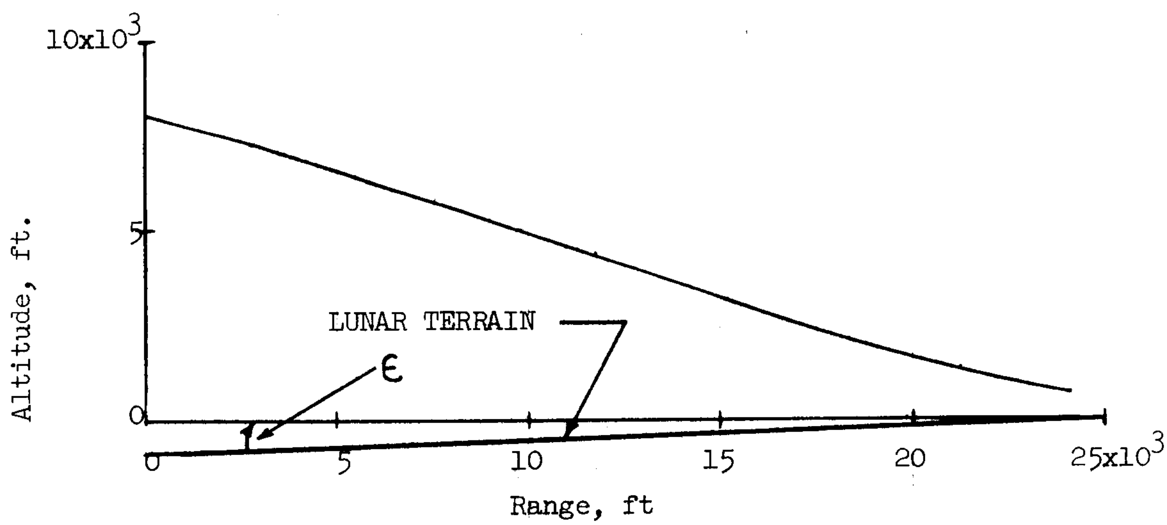
(b) Negative slope - low terminal altitude

Figure 3.- Altitude vs. range profiles for a 2-deg sloping lunar terrain.



(c) Negative slope - low initial altitude

ϵ = 2 deg



(d) Positive slope - high initial altitude

Figure 3 (concluded).

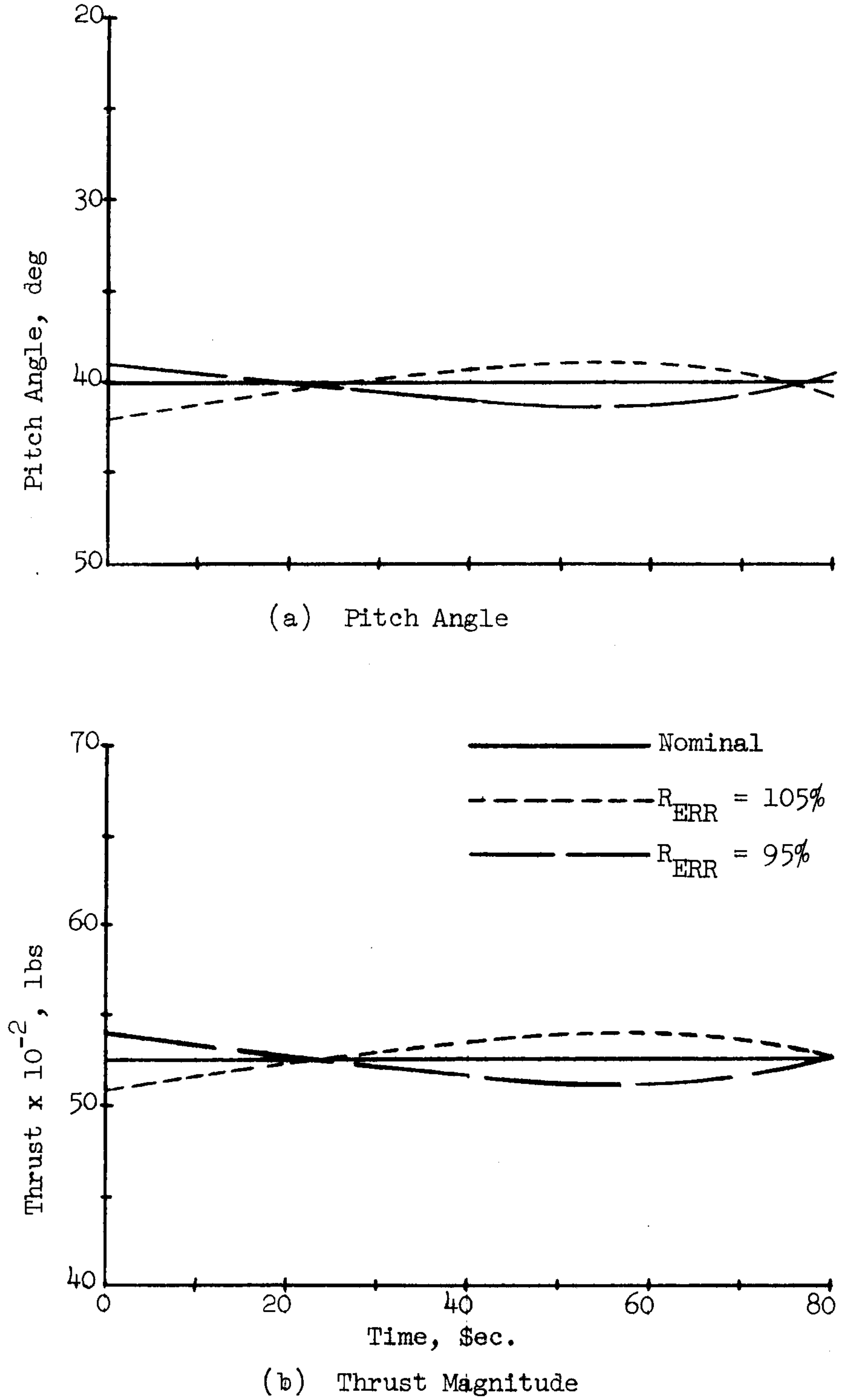
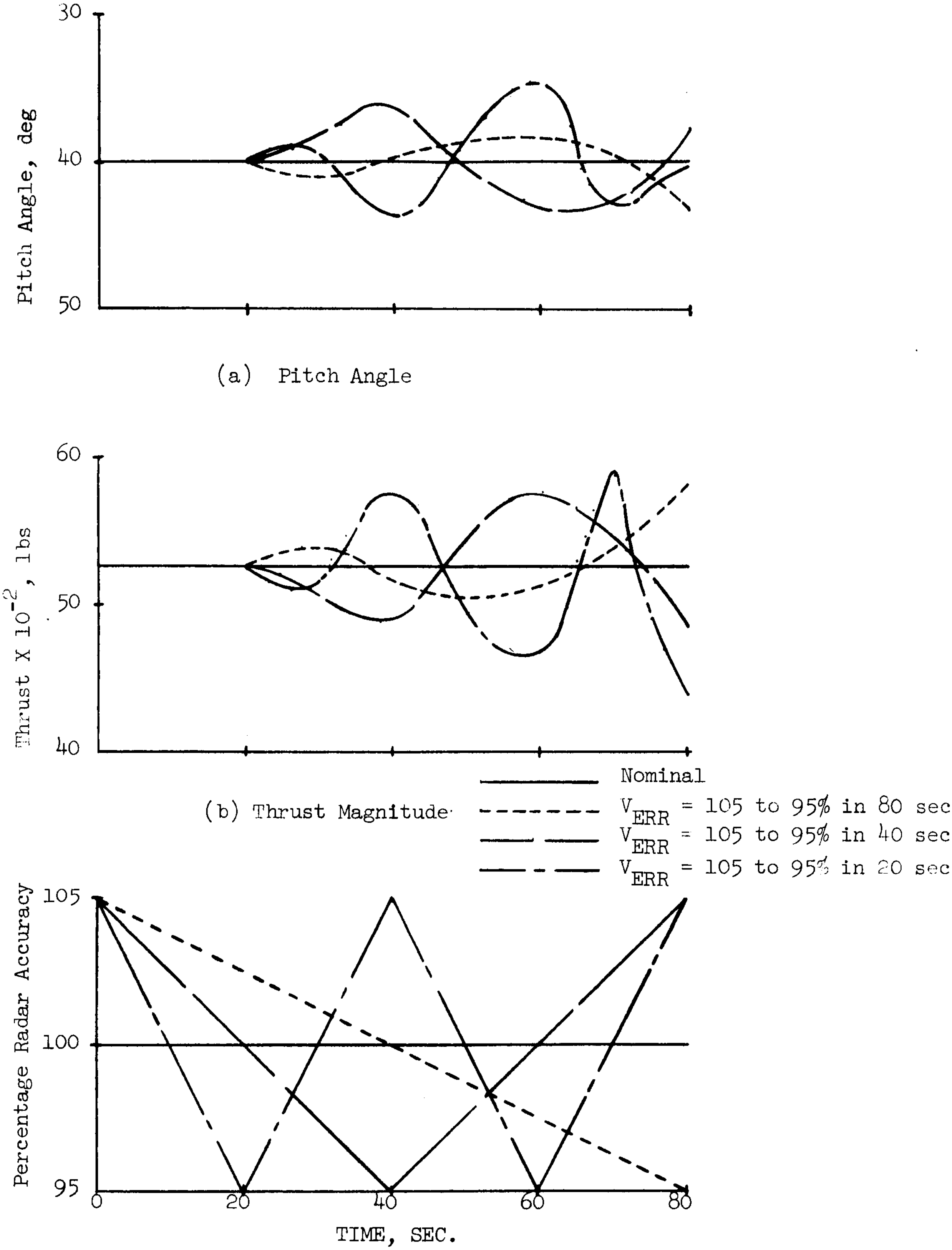


Figure 4.- Time histories of guidance commands for altitude radar error

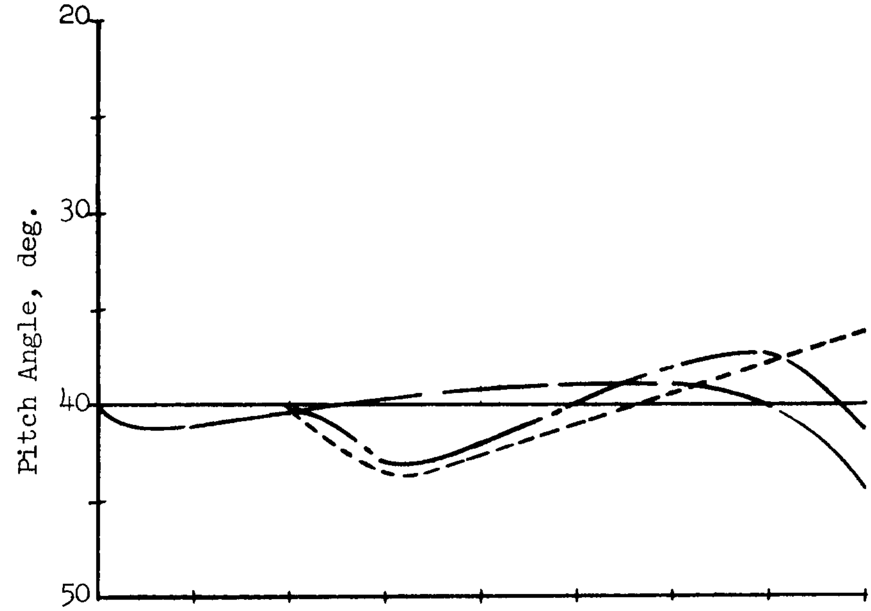


(a) Pitch Angle

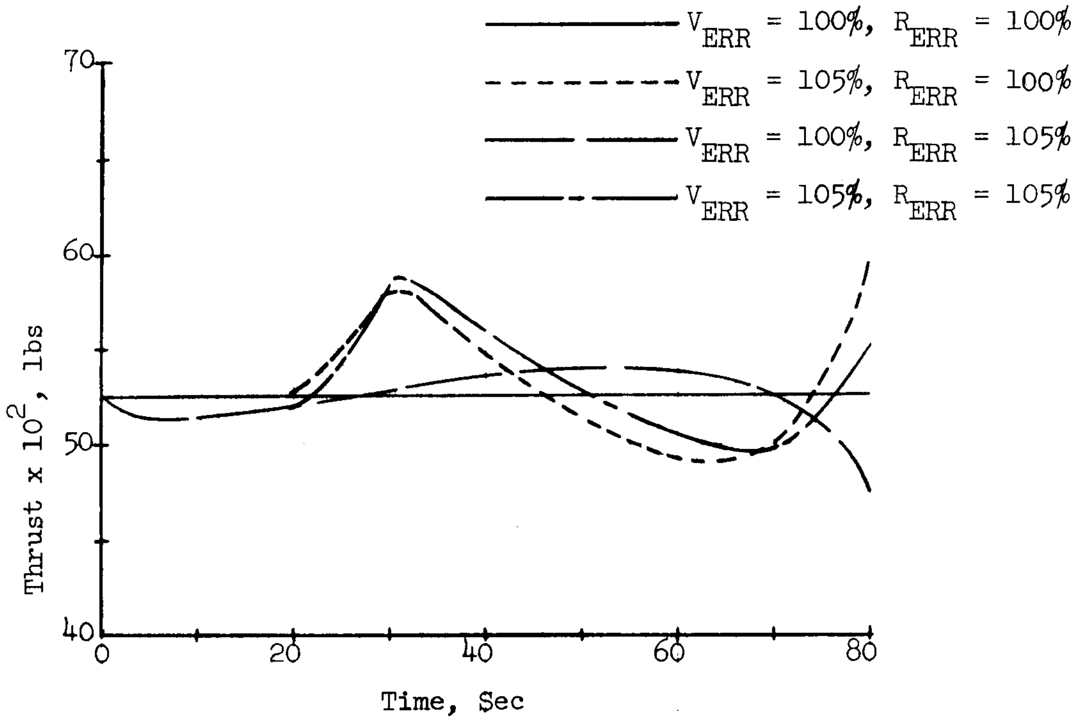
(b) Thrust Magnitude

(c) Profiles of Sawtooth Velocity Radar Accuracies

Figure 5.- Time histories of guidance command and the profiles for sawtooth velocity radar errors.

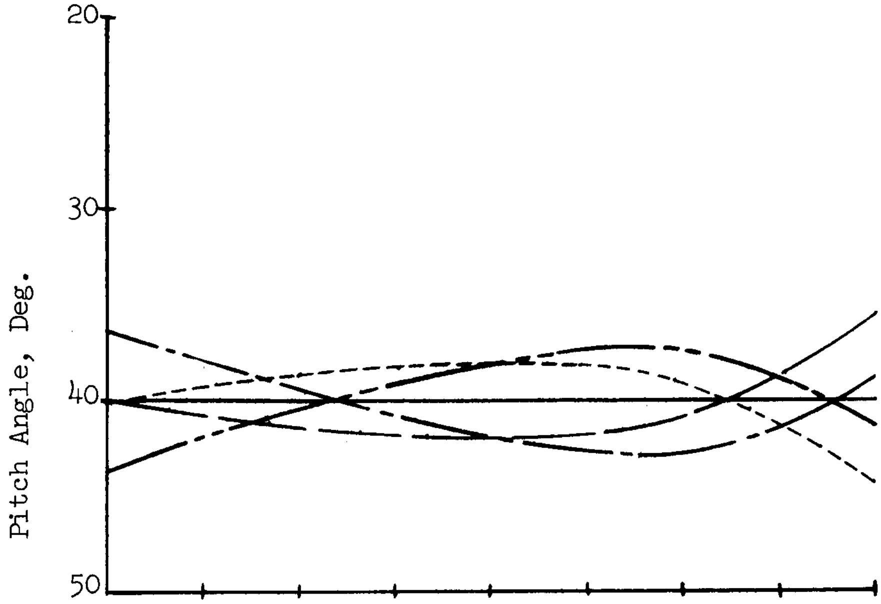


(a) Pitch Angle

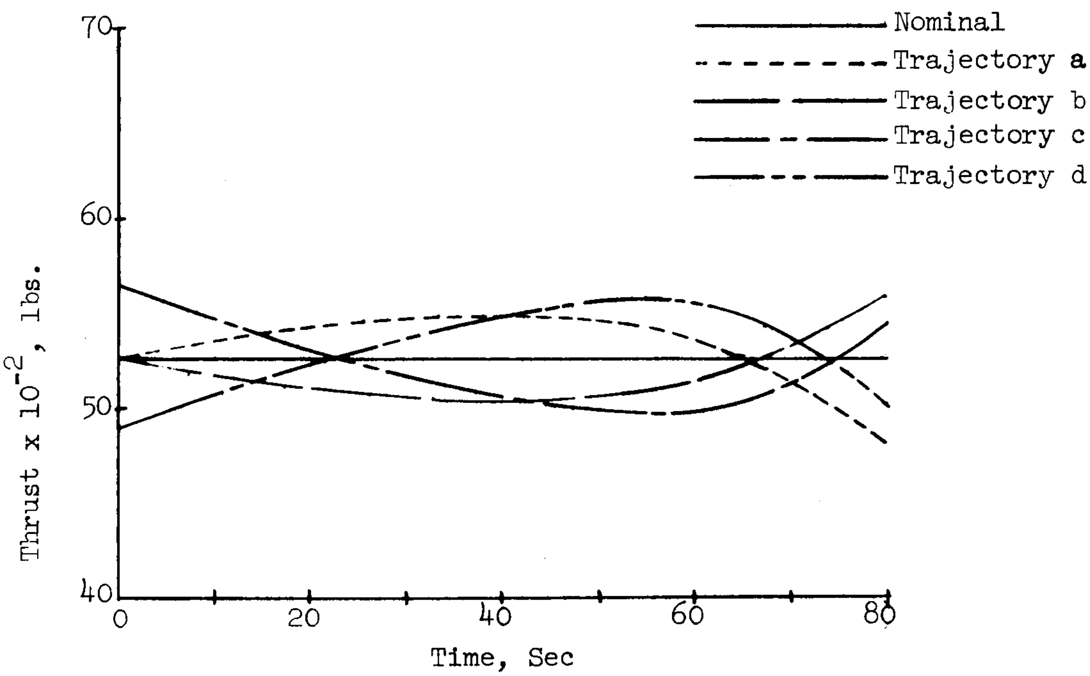


(b) Thrust Magnitude

Figure 6.- Time histories of guidance commands for combinations of constant velocity and altitude radar errors



(a) Pitch angle



(b) Thrust magnitude

Figure 7.- Time histories of guidance commands for a 2-deg. sloping lunar terrain.